TECHNICAL REFERENCE DOCUMENT

SUPPORT SUSTAINABLE AGRICULTURE AND FORESTRY, AND COMBAT LAND DEGRADATION

1. Introduction

Production of food and fiber, and the maintenance and restoration of soil and water resources are vital to human welfare. Increasing population is creating greater demands for resources, generating more waste, and is consequently straining the capacity of the environment to support human activity. High consumption and industrialization, disparity of distribution patterns of wealth and land, conflicting politics, poverty, and inefficient technology interact with population growth to further tax the ability of natural resources, agriculture and forestry practices to provide for the estimated 6 billion human inhabitants of the Earth. Consequently, sustainable land use and the prevention of land degradation have become domestic and international priorities.

Agricultural, forest, pasture and range landscapes are important for commodity production, sources of water for municipal and industrial use, wildlife habitat, and a variety of other ecosystem services. The emphasis is on land directly used for production, and for surrounding natural areas. Landscape health affects air quality, and water quality, and thus has potential consequences for human health.

Production security provides a foundation for domestic and international economies. Earth observations are used as criteria for decisions to maintain the security of production resources and assure competitive global economy participation. The supply of food, fiber, ecosystem services, and market information can often be linked to simple information needs.

An objective of good environmental stewardship is combating land degradation. An essential element of stewardship includes monitoring public and private lands for indicators of decreased physical capacity of a landscape to produce food and fiber, function as a viable watershed, and maintain functional assemblages of plant and animal species for ecosystem health. By gaining a better understanding of the environment through Earth observations and models, links between cause and effects of land use practices, and natural or man-made changes can be made.

2. User Requirements

Of the nearly 2.3 billion acres of land in the United States, approximately 650 million acres, or 28 percent, are owned by the Federal Government. Approximately 90 percent of all non-Federal lands, or about 1.5 billion acres, are in cropland, rangeland, pastureland, and private non-industrial forestland managed by millions of individuals. Thus, users of Earth observations range from strategic to production level decision makers in Federal, Tribal, and State governments, and industry, including land managers and individual producers.

Producers are interested in their own land and production of competing producers both domestically and internationally. The success or failure of crops in one region of the globe can affect supply and demand elsewhere and can thus influence decisions as to how much to invest in production, what to produce, and how much to plant. Assessing timber resources for harvestable lumber prior to making a decision to purchase frequently involves observations of foreign forests. Developing countries require Earth observations to inventory and manage natural resources, set priorities for land use, and help them compete in global markets as producers.

Earth observations are required to 1) continually monitor domestic and foreign production, and 2) conduct on-going audits of the status of baseline resources. Reasons for (1) are: to assure food security, maintain marketplace competitiveness, improve production efficiency, and improve risk management. Reasons for (2) include: assure sustainable production and future resource use, maintain or improve landscape health, monitor the progress of recovery from damage caused by episodic weather events, over-use, pest infestations, etc. Producers require continual feedback on within-season production progress for remedial actions when factors limiting production such as pests, water, nutrient deficiency, or drought intervene. Both requirements support government activities such as managing public lands, monitoring for compliance with land use agreements and resource conservation legislation, and detecting signs of bioterrorism.

Earth observations are widely used for assessments of production and resource conditions at a point in time (i.e. a “snapshot”). However, there is a need to move beyond the emphasis of “snapshot” assessments to the incorporation of observations into models that can be used to predict yield or resources status as a consequence of future climate, management, biotic, and abiotic changes. Modeling of landscape systems and human land use activities is accomplished through careful *in situ* monitoring and analysis of factors such as soil parameters, plant productivity indications, water resources, and species composition and abundance. Remote sensing further contributes basic data for modeling and can provide a tool for interpolating or “scaling up” *in situ* observations to coarser spatial scales.

There is a critical need to identify observations or metrics that can serve as indicators of environmental health status. Environmental indicators are scientific measurements or quantities derived from measurements that track environmental conditions over time. Indicators help measure the state of our air, water, biotic, and land resources, the pressures on them, and the resulting effects on ecological and human health. Indicators can be used to track progress towards making the air cleaner, the water purer, maintaining biodiversity, and protecting landscapes.

Major issues associated with sustainable agriculture, forestry, and responsible resource stewardship include:

- Monitoring domestic and foreign yearly yields and harvests of food, and fiber production at field, local, regional and global scales.
- Measuring soil erosion from wind and water.
- Detecting impacts of global change, especially climate.
- Detecting the presence of, and then monitoring the spread of invasive species, including plants, animals, insects and diseases affecting agriculture, forestry, and natural resources,
- Detecting, and measuring, contamination of soil, water, and air resources, including dispersion of pollutants.
- Detecting indicators of landscape health (i.e. impacts of resource degradation on agroecosystems, and natural ecosystems)
- Measuring resources involved in the development and production of biofuels.
- Detecting, and measuring, the impact of, and the progress of recovery from, episodic catastrophic events such as drought, flood, hurricanes, tornadoes, volcanic eruptions, earthquakes and wildfires.
- Detecting the effects of bioterrorism (e.g. plant diseases, water-born pathogens), and monitoring progress of remediation.
- Metrics for maintenance of soil quality, especially organic matter, and chemistry.
- Detecting and measuring landscape factors indicating compliance with agreements between landowners/operators and federal and state agencies (e.g. Conservation Reserve Program (CRP), easements, timber sales, rangeland management).
- Detecting and measuring landscape factors indicating compliance with international treaties and agreements.
- Identifying pathways that transport hazardous waste, and measuring the amounts and ultimate fates of waste.
- Measuring the status and changes of habitat and effects on plant and animal biological diversity.
- Measurements to identify and quantify factors influencing water quantity and water quality and air quality.
- Measuring greenhouse gas dynamics, especially factors relevant to carbon sequestration, and climate change.
- Measuring the long-term effects of the use of ground water.

Data requirements are guided by user needs and a recognized set of principles. Measurements must be:

- Timely: there is a need for frequent updates of observations; turn-around times from measurement and processing to delivery to users must be rapid.

- Consistent: measurements must be repeatable through time and space with precision.
- Calibrated: observations must be conducted in a manner that achieves a high degree of accuracy with a quantitative understanding of the errors associated with measurement and processing.
- Sustained: planned for long-term acquisition, or until a technological innovation arises that can provide a superior information solution.
- Comprehensive: providing a clear understanding of the status of, and changes in agriculture, forest, range, and natural area resources.
- Relevant: few decisions affecting natural resource management are made based on a single piece of information, thus Earth observations must be conducted with attention to their context of use.
- Standardized: compatible formats, units, and calibrations are needed to allow observations from diverse sources to be integrated.

Attention must also be focused on:

- Spatial scale of observations: ranging from detection of variations within individual farm fields to observing global conditions
- Linking observations across scales without magnifying errors.
- Time-sensitive observations that must be rapidly acquired, processed, and reported.
- Validation of observations.
- Collection of data for use with models

3. Existing Capabilities and Commonalities

Many users, especially government services, rely heavily on remotely sensed data from aircraft and satellite systems as a starting point for information. Industry users range from large corporations to individual producers. Users have varying levels of image-handling and analysis expertise. Use of the skills of manual image analysis (i.e. photointerpretation), are still widespread, whereas computer aided image processing requires specialized training and tools and is not as prevalent among users.

Wavelengths of interest include visible, near infrared, short wave infrared, thermal infrared, microwave and RADAR. Optical wavelength multispectral systems dominate use because of their widespread availability. There is considerable research on applications of hyperspectral systems, despite the limited availability of these instruments. Technological advancements of imaging LIDAR and demonstrations of its utility are increasing.

Remotely sensed data from satellites come from a variety of systems. The systems encompass high spatial resolution systems such as Ikonos, Quickbird and SPOT, the medium spatial resolution of Landsat Thematic Mapper (TM) and Terra ASTER, and spatially coarse resolution systems such as Terra-MODIS, Aqua-MODIS, SPOT-Vegetation, AVHRR, and GOES. Medium and coarse resolution satellite data are accessed whenever possible because of its multi-temporal global coverage capability, and attention to calibration by providers. High resolution satellite data are especially useful for areas where collection of data from aircraft is either infeasible or prohibitively expensive. The use of high-resolution satellite data has been limited by its relatively high cost, and licensing restrictions. The use of optical wavelength remote sensing systems is severely limited in many cases by the availability of infrequent coverage due to cloud cover.

Radar observations are accessed from RADARSAT International, and from airborne systems deployed for specific objectives. Microwave systems are more limited in their use, primarily via satellite for SSM/I. Some airborne systems are used, however, for research purposes, and topographic mapping, radar is now being offered by commercial firms.

Airborne systems are of major importance to many government, industry and non government organization (NGO) users. There is considerable use of photographic systems ranging from small format aerial photography to large format aerial photography. Color and color infrared are preferred for most applications. Digital cameras and multispectral systems are increasingly used. There is limited use of hyperspectral imaging due to its decreased availability, high cost, and need for specialized expertise during analysis. However, there is an increasing and robust body of research on the use of hyperspectral systems to measure leaf and canopy chemistry, crop yields, and plant health, not only for agriculture, but also as a general indicator of biosphere condition. Airborne thermal systems are also being increasingly used in agriculture and forestry with a primary application being fire detection and mapping.

In situ observations are conducted from both automated systems, and by individuals or organizations on an "as-needed" basis for specific objectives. A number of existing *in situ* monitoring systems and programs could serve as a developmental model of future global ground based monitoring systems. Some of these include the projects and systems listed as Table.1.

Baseline inventories of resources such as soil characteristics (texture, organic content, pH, moisture retention capacity, etc.), topography, watershed boundaries serve as base map information and are used for within-season production management and for pre-season production strategy formulation. Currently, most of these factors are measured *in situ* with samples taken at scattered locations that are interpolated for areal coverage. Research on models such as pedotransfer functions is providing tools to further exploit basic soils data currently available to domestic users via STATSGO and SURGO data bases. Individual domestic and some foreign producers now have the capacity to map topography using GPS equipment mounted on farm tractors, combines, sprayers, etc. Commercial firms offer services that provide information such as topography, soil texture, soil pH, soil organic matter, soil nutrient status, and broadcast GPS differential correction signals.

Table 1 Examples of U.S. Government Programs collecting detailed *in-situ* environmental data

Program	Types of Data	Agency	Website
AIRNow	Air Quality Data	USEPA	http://www.epa.gov/airnow/
BBS	Breeding Bird Survey	USGS	http://www.pwrc.usgs.gov/bbs/
CERCLIS	Hazardous Waste Sites	USEPA	http://www.epa.gov/superfund/sites/cursites/
EMAP	Environmental Monitoring & Assessment Program	USEPA	http://www.epa.gov/emap/
FIA	Forest Quality	USFS	http://www.fs.fed.us/pnw/fia/
GAP	Biological Resources	USGS	http://www.gap.uidaho.edu/
NRI	National Resources Inventory	USDA	http://www.nrcs.usda.gov/technical/NRI/
NWIS	Water Quality Data	USGS	http://waterdata.usgs.gov/nwis
STATSGO	Soil Parameters	NRCS	http://www.ncgc.nrcs.usda.gov/branch/ssb/products/statsgo/index.html
PMP	Pesticide Monitoring Program	USDHHS	http://vm.cfsan.fda.gov/~dms/pesrpts.html
REVA	Regional Vulnerability Assessment Program	USEPA	http://www.epa.gov/reva/
USCRN	Climate Observations	NCDC	http://www.ncdc.noaa.gov/oa/climate/uscrn/
GAM	Geographic Analysis & Monitoring Program	USGS	http://gam.usgs.gov/
PINSAT	Pintail Duck Monitoring	USGS	http://www.werc.usgs.gov/pinsat/
BBS	Breeding Bird Survey	USGS	http://www.pwrc.usgs.gov/bbs/
NAAMP	North American Amphibian Monitoring Program	USGS	http://www.pwrc.usgs.gov/naamp/
GWA	Ground Water Atlas	USGS	http://capp.water.usgs.gov/gwa/gwa.html

BEST	Biomonitoring Environmental Status & Trends	USGS	http://www.best.usgs.gov/
CropExplorer	Production Estimates and Crop Assessment Division	USDA-FAS	http://www.pecad.fas.usda.gov/cropexplorer/
AERONET	Aerosol Robotic Network	NASA	http://aeronet.gsfc.nasa.gov/
JAWF	Joint Agricultural Weather Facility	USDA/NOAA	http://www.usda.gov/agency/oce/waob/jawf/
WDC-BTE	World Data Center for Biodiversity & Terrestrial Ecology	USGS/NBII	http://wdc.nbii.gov
SCAN	Soil Climate Analysis Network	USDA-NRCS	http://www.wcc.nrcs.usda.gov/scan/

Weather-related data for irrigation scheduling and determination of microclimate conditions (suitable for species habitat characterization, forecasting the probability of pest outbreaks, potential for forest and rangeland fires, etc.) rely on Federal state, and privately-owned and supported meteorological networks.

Species inventories are conducted for terrestrial and aquatic systems, and in both managed and natural ecosystems. Long term *in situ* monitoring that can provide direct measurements of agricultural and forestry sustainability and land degradation include:

- Species abundance/biodiversity (number of species present per unit area)
- Species density (number of individuals or percent land covered per unit area)
- Native/non-native species ratio
- Degree of infestation by pathogens
- Reproductive success (number of offspring surviving to adulthood)

Species inventories require exhaustive time, effort, and expertise to be completed. For example, the All Taxa Biodiversity Inventory of the Great Smoky Mountains has estimated there are 100,000 species present, excluding bacteria, yet only about 10% were identified when the project started in 1999. Since then, there have been about 3,000 species determined new to the park and 500 of them are new to science.

The following are the most significant common information needs:

- Land cover and land use within, and surrounding, a particular landscape or ecosystem: the required detail for meeting program objectives ranges from highly specific (crop type, species, plant community, etc.) to general (agricultural, forested, urban, etc.). Definitions of land cover vary by application and by spatial resolution, as do requirements for accuracy. Imagery ranging from panchromatic aerial photography to coarse resolution multispectral satellite data is used for land cover and land use analysis.

- Change detection of land cover, and plant and animal species composition: it is important to assess short term changes such as within a growing season or long term ranging from years to decades or more.
- Weather data for domestic and international agricultural monitoring programs: There is considerable reliance on these data by organizations from sources such as NOAA, NASA, USAF, and WMO. Weather data are accessed in the form of weather station observations, radiosondes, multispectral satellite imagery, reports from weather observers, and other automated instruments such as AERONET for atmospheric optical properties. Some secondary data are obtained through measuring the quantity and timing of the streamflow in the Nation's rivers.
- Geolocation via the Global Positioning System (GPS): this has become a standard component of almost all Earth observations. Real-time differential GPS methods access U.S. National Differential GPS base station signals, FAA Wide Area Augmentation System (WAAS) signals, or commercially-available signals. Post-processed differential GPS corrections using Continuous Online Reference Station (CORS) data or other local base station data remain an important source of data for many applications. Kinematic GPS is used for *in situ* and airborne applications. The current information revolution in agriculture, forestry, and natural resources management is largely focused on a demand for geo-located Earth observations.
- Field data in the form of animal specimen locality records and vegetation plots are used for modeling habitat distribution, and calibrating remotely sensed spatial data, as well as for validation and accuracy assessment. Field data for operational purposes are frequently the most expensive to acquire.
- Topography in the form of a digital elevation map (DEM): This is commonly used as an element of base maps. Accuracy requirements range from sub-meter to tens of meters. Photogrammetric methods still dominate acquisition. RADAR, LIDAR and kinematic GPS are gaining in use. Watershed boundaries are especially important to producers, land managers, and governmental programs focused on soil and water quality issues.
- Soil series maps, and USGS 1:24,000 scale maps depicting waterways, and cultural features, etc. are common sources of base maps for many applications. Use extends beyond suitability for planting to susceptibility to erosion, construction of infrastructure including access routes, etc.
- Long-term data for change detection, calibration of algorithms, and species inventory: There is a need to continue converting historical imagery, maps, field notes, and data sheets to digital form.

A tool commonly used by users is the Geographic Information System (GIS). GIS is employed as a tool during data collection, as a common platform for assimilating data from multiple sources, conducting analysis, and communicating information. Data and information are communicated via tables (i.e. statistics) and maps. Digital maps from a GIS can be used to drive variable-rate within-field planting, irrigation, and agrochemical applications.

The spatial scales for observations range from sub-landscape (i.e. within-field) to global. The time scales range from hourly to decades. Applications demand more accurate and finer scale information as the intensity of land use increases and expands into less resilient soils, and less favorable climatic conditions. Industry needs are primarily for higher spatial and temporal resolution. Higher spatial resolution is also particularly important for many international users. Small cultivation areas and different cultivation practices of many regions of the world often make it difficult to ascertain what parts of a landscape are under cultivation by developing countries.

4. Major Gaps and Challenges

Significant discontinuities of *in situ*, airborne and satellite data exist through space and time. Interpolation of *in situ* data using linear and weighted methods such as kriging has become a standard element of data processing. A lack of timely data often forces a compromise of analysis and ultimately decisions based on the criteria. It is often difficult to engage the services of qualified airborne imagery providers when needed. Agency efforts to acquire complete "snapshot" image and *in situ* observations of the U.S. for baseline resource audits can require several years. Observations of non-U.S. landscapes suffer from a paucity of *in situ* observations of almost all types. Reasons include a lack of technology, availability of trained personnel, access to politically sensitive areas, and competition for limited resources required to adequately fund observation efforts.

The significance of remote sensing imagery as a baseline data source for applications, coupled with concerns about data discontinuities through space and time communicates a strong message from users: there is a critical need for a dedicated operational land-observing system. Although users point to the benefits of Landsat imagery, the specific characteristics of an operational system of this type will incorporate improvements driven by user information requirements. A design element of an operational Landsat-type system will be to eliminate as many spatial and temporal data discontinuities as possible. The development of operational hyperspectral imaging capabilities, both at the aircraft and satellite levels, will significantly enhance the utility of data from land observing systems.

Remotely sensed soil moisture and precipitation are major data gaps. Maps of soil moisture are needed for management of production, drought forecast and monitoring, flood forecasting, and quantification of landscape health. Remotely sensed precipitation is needed to fill gaps of traditional weather station rain gauges and the limited coverage of *in situ* radar (NEXRAD).Other weather and climate-related observations used in models such as incoming solar radiation and CO_2 flux are spatially sparse.

Environmental modeling is relatively spatially imprecise. While models can be very accurate at large scales or for an "average" situation, finer scale heterogeneity in resources and management practices restrict the utility for specific locations. As land management and agriculture applications continue to refine management systems and respond to niche markets, this heterogeneity is likely to be amplified. Similarly, information for profitable and sustainable operational systems will have to be very site specific to be of value. Thus, further model development, model optimization, and model validation are needed. This impacts Earth observations as models 1) often only work for specific geographic regions, ecosystems, and species, and 2) often dictate what observations are to be taken. The complexities of ecosystem structure and function further enforce the need for interdisciplinary teams when building models. It is widely recognized that optimization and validation of models for specific locations and applications are critical. These complexities of landscape structure and function and management practices further enforce the need for interdisciplinary teams that can develop new technologies and methodologies to disaggregate process models to individual sites reliably and efficiently.

Challenges to achieving adequate Earth observations for sustainable agriculture and forestry, environmental stewardship, and maintaining marketplace competitiveness are scientific, technological, economic, and organizational. Data distribution is becoming dominated by use of Internet Web site downloading tools. There is also considerable use of FTP, especially for large data sets. Use of postal services and shipping are still common especially for very large data sets, printed materials, and physical samples. This is especially prevalent for archived data not yet converted to digital form. However, a lack of awareness of and access to data remain significant barriers. The lack of common data formats, units, instrument calibrations, and algorithms for data collection continue to be challenges for exchange and use of data, and more importantly, information derived from measurements. The development of Earth observation technologies has surpassed those currently employed for applications, such that users often lack the benefit of the latest advancements. The ability to rapidly infuse new observations into existing organizational infrastructure is a significant consideration. New or better observations may yield improved information for the application at hand, yet may be difficult to incorporate into an organization's or individual's operating procedures, or may not be comparable with previously collected observations.

The development of decision support systems (DSS) that use Earth observations is now recognized as priority for facilitating the use of Earth observations. The DSS completes the chain of system elements that begins with data acquisition and ends with information delivery to a user within the context of an application. Critical elements for successful DSS adoption include simplicity and flexibility: the system must be convenient to use.

The mission of regulatory agencies and those monitoring for compliance with program agreements and regulations demand accurate observations that are acceptable as evidence when legal action is warranted. Careful attention to the selection of observations that will serve as metrics requires scientific and legal review by non-regulatory science agencies. Attention to the maintenance of confidentiality to insure privacy of participants will be integral to the process.

Expanding and enhancing existing systems such as *in situ* networks or short-term measurement field campaigns are a continuing challenge. Such endeavors, although critical, rarely capture the attention of decision makers allocating yearly resources. Thus, important inventory and survey programs may be limited by funding cycles: monitoring ends with funding, award of graduate degrees. Collecting, synthesizing and interpreting resource health information is an important public service and critical to developing and implementing cost-effective conservation programs.

5. Future Earth Observation Systems that May Fill Gaps

Several future systems will provide data of interest to sustainable agriculture and forestry, efforts to combat land degradation:

- Landsat-follow-on satellite system. Its form is to be driven by user information needs, noting that an 8-day or better revisit time is needed for many agricultural monitoring applications.
- Hydros for mapping soil moisture will provide critically-needed data for many applications.
- NPOESS as a source of high quality coarse scale resolution imagery.
- The next generation of geostationary satellites: the use of imagery from these systems is underutilized. Recent exploitation of these systems suggests that its use is expected to increase.
- Digital airborne systems are expected to gradually replace photographic airborne systems.
- *In situ* automated systems are gaining in reliability and are being expanded. Existing networks include systems such as SCAN, AERONET, NSIP, FLUXNET, automated weather stations, etc. Locations of such systems on LTER and USDA experimental watersheds are expected to expand as these research facilities expand and become long-term.

Mechanisms for the delivery of observations from these systems are needed by all users.

The IWGEO agriculture team is currently discussing the following topics for the conduct, sharing and use of Earth observations needed to support sustainable agriculture and forestry, and combating land degradation:

- The greatest unfulfilled requirement is the need to implement an operational Landsat-type satellite remote sensing system that can deliver time-sensitive information.
- Involvement of users in decisions regarding the conduct of observations, and especially the delivery of data and information to insure that information from Earth observations is available to users in a manner that is rapid and convenient.

- Linking observations across scales while constraining errors will require specific attention to research on scaling methodologies.
- Integrating Earth observations into decision models employed by decision makers at local and strategic levels, and guiding how, when and where to conduct Earth observations by inputs needed for the models.
- Maximizing the awareness of and access to data via new organizational operating procedures, and communication mechanisms.
- Conducting research to optimize models and systems for specific applications and geographic locations.
- Fostering partnerships and collaborations across disciplinary, organizational, national and international boundaries to address Earth observations needs, andevaluating the scientific, technological, and organizational requirements to accomplish this.
- Developing organizational mechanisms and technologies to ensure that long-term observations are made and centrally archived.
- Standardizing and coordinating *in situ* data collection.

A dedicated global land observation system, based on *in situ*, airborne, and satellite systems, both research and operational is suggested. An agricultural monitoring system would function as part of the system. A critical element will be developing the technology to make Earth observation data available to users rapidly and conveniently. Making such a system successful will require users at both strategic and production levels to re-examine what types of Earth observations are used, how the data are used, how the data are accessed, and how the data are incorporated into an organizational infrastructure for processing and analysis. The improvement of the utility of Earth observations will happen through education, the development of DSS, improved dissemination, standardization, and research.

6. Interagency and International Partnerships

Partnerships exist between private land managers, Federal agencies, Conservation Districts, Resource Conservation and Development Councils, state and local conservation agencies and organizations, NGOs, state, local and tribal governments, rural communities, businesses, universities, and others. Cooperation among these organizations seek to increase agricultural productivity and efficiency, conserve natural resources, improve the environment, and enhance quality of life for rural areas. Federal, State and industry partners actively engage in education, research and conduct of Earth observations. Individual companies exist that specialize in the conduct and analysis of specialized Earth observations.

Types of partnerships include formal agreements that may include exchange of resources, or informal agreements to employ common standards, formats, strategies, etc. International partnerships foster education, research information management and aid via explicit political agreements or informally by scientific communities. Information management and exchange are emphasized by the participants. There is also exchange of Earth observations by international industries. Satellite and airborne data such as SPOT, VMI satellite data are examples. However, U.S. commercial and much foreign imagery is licensed. Licensed data can restrict its distribution and limit partnerships.

The most successful partnerships to address challenging agricultural and environmental issues cross disciplines, agencies, and national, and international boundaries. The Multi-Resolution Land Characteristics (MRLC) consortium, for example, was formed during 1992 between several Federal agencies to share the cost of acquiring satellite-based remotely sensed data. The MRLC consortium included the USGS, EPA, NOAA, USFS, NASA, and BLM. The MRLC leveraged common user requirements with the efficiency of combined federal agency purchase to acquire a national dataset of Landsat Imagery and to develop several LULC datasets. From the 1990s through the present, the MRLC resulted in several successful national mapping programs, including the: (1) Coastal Change Analysis Project (C-CAP) administered by NOAA; (2) Gap Analysis Project (GAP) directed by the Biological Resources Division of the USGS; and the National Land Cover Data (NLCD) project directed by both the USGS and EPA.

Industry utilizes formal and informal partnerships. Commodity groups, cooperatives, service/consultant relationships, and trade associations are examples. Relationships between agribusiness and producers are often especially critical during the adoption of new technologies and associated products. Open communication of product performance, and guidance on its use between users is often the key to the adoption of innovative technologies. Agreement on engineering standards, data standards, and software and hardware compatibility are dealt with via partnerships. The role of universities, via extension and research organizations is recognized as important to successful partnerships among users, between data providers and users, and between data providers.

7. U.S. Capacity Building Needs

Capacity building is the development of human skills and capabilities, such as leadership, management and technical expertise. The United Nations Development Program includes the 1) creation of an enabling environment with appropriate policy and legal frameworks, 2) institutional development, including community participation, and 3) human resources development and strengthening of managerial systems, as three critical elements for capacity building. Ensuring the availability of Earth observation systems to support sustainable agriculture and forestry, and combat land degradation domestically and globally will require an adherence to these elements via education, research, and team building.

Education builds scientific, agricultural, and environmental literacy. It recruits, retains, and graduates the best and the brightest of a diverse population, ensuring the value of future research. Multidisciplinary education to include new technologies, especially geospatial tools is an emerging trend. Education is also of benefit to Earth observation users and Earth observation providers. There is also a need to communicate the value of Earth observations to decision makers, and the public. This includes expanding awareness of the utility of various Earth observations, such as satellite data, to new applications.

Research and development are conducted by government, non-governmental organizations, universities, and industry to address specific application requirements, and translate science to specific applications at specific scales for specific locations. Incentives for continued expansion of knowledge of Earth systems, and technological innovation, will be critical. Improved communication between users of Earth observations and researchers will ensure that the right research questions are investigated, and that new Earth observation-appropriate technologies are developed. Information needs and opportunities for improved technologies for Earth observations should guide research.

Solving specific problems will require focused teams to address specific problems across disciplines, agencies, across national and international boundaries. Research that integrates biophysical, social, and economic skills is needed in areas such as detecting and responding to bioterrorism, regional water and air quality, biodiversity management, and the incursion of invasive species.

Research and development to meet information needs by translating science to technology require partnership teams to pose and solve problems across disciplines, agencies, national, and international boundaries. International aid and cooperative research programs are focused on providing assistance for Earth observation programs and training scientists within developing countries.

Training scientists about the importance of metadata in all areas of data management is being undertaken by the National Biological Information Infrastructure (NBII), in their "Training the Trainer" program, which is offered to government, NGO, and academic participants at national and international levels. The NBII offers a variety of workshops on the Federal Geographic Data Committee's metadata standard, with a specific focus on the Biological Data Profile.